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THE OCCURRENCE OF THE SHARK GENUS *TRIGONOTODUS* FROM THE EOCENE OF MONMOUTH COUNTY NEW JERSEY

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ABSTRACT- The genus *Trigonotodus* was originally described from the Eocene of Kazakhstan and has since been recorded from the Eocene of Uzbekistan, England and Morocco as well as the Oligocene of South Carolina. To date, no occurrences of the genus have been recognized from the Eocene of North America. Here we report on three teeth of *Trigonotodus* cf. *tusbairicus* collected in Monmouth County, New Jersey from a lag deposit separating the middle Eocene Shark River Formation and the early Miocene Kirkwood Formation. These specimens are referred to the Shark River Formation and are the first examples of the genus to be reported from the Eocene of North America.

INTRODUCTION

The selachian genus *Trigonotodus* was erected by Kozlov in Zhelezko & Kozlov (1999), with the type species, *Trigonotodus tusbairicus*, being described from the middle Eocene (Bartonian) of Kazakhstan. This taxon has been described as a giant 'thresher' type shark with cusped teeth. An unnamed species of *Trigonotodus* from the early Eocene (Ypresian) of Kazakhstan (Kozlov unpubl. data) was documented by Cappetta (2012) along with other undescribed specimens of *Trigonotodus* from the Ypresian of England (Ward pers. comm.) and Uzbekistan as well as the Priabonian of Morocco (Cappetta 2012). Another species was described from the Oligocene (Rupelian) Ashley Formation of South Carolina and named *Trigonotodus alteri* (Kozlov, 2001). Here we describe three *Trigonotodus* teeth recovered from the Paleogene of New Jersey. This is the first reported occurrence from the state of New Jersey as well as the first occurrence of the genus from the Eocene of North America.

Previous studies of the Eocene and Miocene elasmobranchs of New Jersey, including Fowler (1911), Gallagher et al. (1996) and Maisch et al. (2015), did not identify *Trigonotodus* (or *Trigonotodus*-like teeth for those published prior to 1999) occurring in the Eocene of New Jersey. No other report has documented the occurrence of the genus in the Eocene of North America. Specimens were recovered from two different temporally-mixed localities in Monmouth County, New Jersey (Fig. 1) where the Eocene Manasquan and Shark River formations as well as the Miocene Kirkwood Formation are exposed along the banks of creeks and rivers.

GEOLOGY

There are several Paleogene and Neogene formations exposed at or near the surface in southeastern Monmouth County, New Jersey (Fig. 2). The oldest of these is the Manasquan

Formation, which is early Eocene (Ypresian) in age. It correlates with nannofossil zones NP 10-13, suggesting an age of 55-50 million years (Sugarman et al., 1991, Sugarman and Stanford, 2006). The Manasquan Formation consists of a lower, clayey, quartz-glaucinite sand layer (the Farmingdale Member of Enright, 1969), which is exposed along the Manasquan River near Farmingdale, Monmouth County, and an upper, fine-grained quartz sand or silt layer (the Deal Member of Enright, 1969), which is exposed near Deal, Monmouth County (Enright, 1969; Sugarman and Stanford 2006). This formation represents a continental shelf deposit, with water depths up to 750-100 meters deep. Macrofossils that correlate in age with the Manasquan Fm. have been found in gravels at stream and brook localities in and around Farmingdale and Deal, NJ as well as both the Shark and Manasquan River Basins. These fossils include chondrichthyan and osteichthyan teeth as well as lignified plant material (DJE pers. observ.).

Lying unconformably above the Manasquan Formation is the Shark River Formation which is middle to early late Eocene (Lutetian-Bartonian) in age (Sugarman and Stanford, 2006; Uhen, 2014; Maisch et al., 2015). The Shark River Formation is composed of glauconite as well as medium to coarse grained, light brown to medium gray silt and clay. The formation is locally indurated near the top and noncalcareous throughout (Richards et al., 1962; Sugarman and Stanford, 2006). Exposures are found at localities near Farmingdale, NJ, along the Manasquan and Shark rivers and in several tributaries of Deal Lake near Asbury Park. Most outcrops are small, being less than 3 meters in height. The Shark River Fm. consists of two cycles (informal members): both of which have a glauconite sand layer present at the base and a tan to brownish clay/silt present at the top. The upper cycle is referred to the informal Squankum Member and is dated between 41.2 – 40.5 million

years ago (Browning et al., 1996; Sugarman and Stanford, 2006). The Squankum member represents open shelf deposition, with water depths of 30-75 meters (Sugarman and Stanford 2006). The fossil remains of invertebrates, chondrichthyans and osteichthyans have been recovered from the Shark River Formation.

Above the Shark River Fm. is another unconformity that separates the Kirkwood Formation from the underlying Shark River Fm. The Kirkwood Fm. is early Miocene (Aquitania-Burdigalian) in age, dated to approximately 21 million years ago (Isphording and Lodding, 1969; Isphording, 1970; Sugarman et al., 1993; Sugarman and Stanford 2006). It is comprised of sands and clays and is subdivided into four members: Belleplain, Wildwood, Shiloh, and a lower member now called the Brigantine (referred to as the Asbury Park Member locally) (Sugarman et al., 1993, Maisch et al., 2015). Upper sand layers are composed of fine- to medium-grained, light-yellow to white sands. Thick-bedded layers of interbedded fine-grained sand and gravelly, coarse- to fine-grained sand are present in upper strata (Sugarman et al., 1991; 1993). Lower layers consist of clays which are dark-gray and micaceous, containing lignite. The lower, dark clayey unit, the Brigantine Member (Asbury Park Member), is exposed in and around Farmingdale in Monmouth County and a few cuts along the Manasquan and Shark rivers. Where the Kirkwood overlies the Shark River Formation, the presence of a lag deposit is the source of many fossils. This lag layer exhibits a range in thickness from undetectable up to 10 cm and contains fossils of both the Miocene Kirkwood and Eocene Shark River formations. (Uhen, 2014; Maisch et al., 2015). The Kirkwood Fm. represents shallow marine (less than 30 meters), marshes, bays and tidally influenced freshwater deposits.



Figure 1: Map showing the region of southern Monmouth County, New Jersey where the specimens were collected.

The largest and best preserved of the three specimens (NJSM 26067) was discovered by Michael W. O'Shea while sifting stream gravel at a temporally mixed, Eocene/ Miocene site in southern Monmouth County, New Jersey. Since this specimen was not recovered *in situ* its precise age is uncertain however the preservation of the tooth is consistent with other Eocene teeth from this locality. This specimen most likely originated from either the Shark River or Manasquan formations.

The other two specimens (NJSM 26068 and 26069) were collected at a second locality in southern Monmouth County, New Jersey by the lead author. These two specimens were collected *in situ* from the fossiliferous Shark River Formation lag layer, which contains temporally mixed middle Eocene and early Miocene fossils. The exact locations of both sites are on file at the New Jersey State Museum (NJSM) and can be requested by researchers.

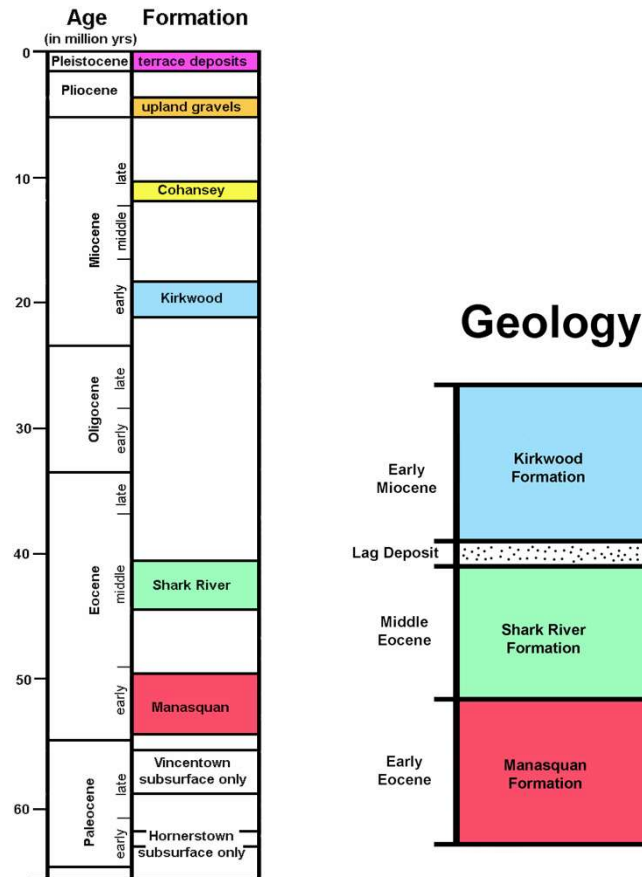


Figure 2: Geology of the region where teeth were collected (after Sugarman and Stanford, 2006).

SYSTEMATIC PALEONTOLOGY

Class Chondrichthyes (Huxley, 1880)

Order Lamniformes (Berg, 1958)

Family Alopiidae (Bonaparte, 1838)

Genus *Trigonotodus* (Kozlov in Zhelezko & Kozlov, 1999)

***Trigonotodus* cf. *tusbairicus*. (Kozlov in Zhelezko & Kozlov, 1999)**

Material- Three teeth assigned to *Trigonotodus* cf. *tusbairicus* (Kozlov in Zhelezko & Kozlov, 1999) in the collections of the New Jersey State Museum; NJSM GP 26067, 26068, and 26069, Fig. 3.

Description- The largest of the three teeth, NJSM GP 26067, (Fig. 3 A-B) measures 12.1 mm in crown height (CH) and 15.7 mm in crown width (CW). A

second tooth, NJSM GP 26068, (Fig.3 C-D) measures 10.4 mm in CH and 11.9 mm in CW. The smallest specimen, NJSM GP26069, (Fig. 3 E-F) measures 7.8 mm in CH and 11.6 mm in CW. All three teeth possess robust, wide roots and small lateral cusplets. The length of the crowns is short in relation to the size of the roots. The teeth are similar to *Otodus obliquus* and *Jaekelotodus trigonalis* in appearance but a raised enameloid bulge on the labial side overhanging the root lobes identifies these teeth as belonging to the genus *Trigonotodus*. The *Trigonotodus* teeth are further differentiated by not having a 'chevron' or 'bourlette' lacking enameloid on the lingual surface as seen in *O. obliquus* or the strong nutrient groove and multiple cusplets seen in *J. trigonalis*.

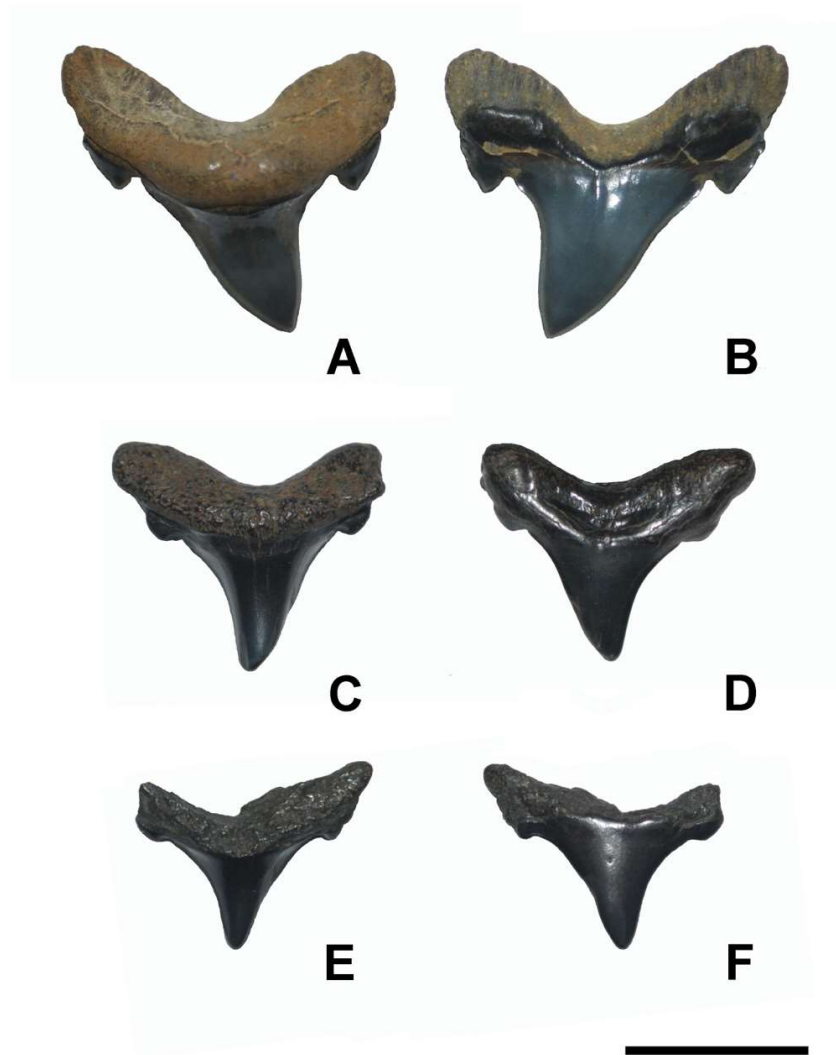


Figure 3: *Trigonotodus cf. tusbairicus* teeth from Monmouth County, New Jersey. A-B Stream gravel, Monmouth County, NJ. C-F Eocene/Miocene lag deposit, Monmouth County NJ. Orientations: A, C, E equal lingual view. B, D, F equal labial views. All scale bars equal 1cm.

DISCUSSION

These three teeth are assigned to *Trigonotodus cf. tusbairicus* based on the morphological similarities with the figured holotype and the similar age of the specimens. However, we also recognize these specimens could represent a separate, undescribed species from the Western Atlantic. Due to the small sample size, we feel it is more conservative to associate these specimens with the previously described taxon.

The genus *Trigonotodus* has not previously been recorded from New Jersey. These three specimens

compare closely with Eocene *Trigonotodus tusbairicus* teeth collected from Kazakhstan (Kozlov in Zhelezko & Kozlov, 1999). This discovery questions the hypothesis of Kozlov (2001) who posited that *Trigonotodus* evolved in the Turan Sea (present day Kazakhstan and Uzbekistan) during the Bartonian (Eocene) and then dispersed into the Atlantic Ocean by the late Priabonian (Eocene) or early Rupelian (Oligocene). The presence of *Trigonotodus* in the western Atlantic Ocean during the Lutetian-Bartonian, Shark River Formation, eastern Atlantic and Uzbekistan during the Ypresian (D. Ward pers. comm.) and the Priabonian of Morocco (Capetta,

2012) suggests the genus was much more widespread earlier in its evolution and likely did not evolve in the Turan Sea. These earlier occurrences in the western Atlantic also provide a more parsimonious explanation for the presence of *Trigonotodus alteri* in the Ashley Formation (Rupelian, early Oligocene) of South Carolina.

The presence of *T. cf. tusbairicus* in the Shark River Formation of New Jersey also indicates that the genus *Trigonotodus* was inhabiting shallow coastal waters during the Lutetian/Bartonian. This is also in contrast to Kozlov (2001) who suggested the genus evolved in deeper, tropical to sub-tropical waters of the Turan Sea during the middle Eocene and spread to coastal waters in the western Atlantic by the Oligocene and Miocene. These New Jersey records suggest that the genus is much more widespread during the middle Eocene, despite being rare, and researchers should revisit collections to look for additional records.

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